4. Method

4.1. Data

4.1.1. Properties

Sources. Daily, hourly, and n-minute (defined below) measurements of precipitation from various sources were used for this project (Table 4.1.1). Figure 4.1.1 shows the locations of daily stations, including SNOTEL (defined below), in the project area. Figure 4.1.2 shows the hourly and n-minute stations.

The National Weather Service (NWS) Cooperative Observer Program's (COOP) daily and hourly stations were the primary source of precipitation gauge records. The following data sets of COOP data were obtained from National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC):

- Hourly data set: TD3240
- Daily data set: TD3200 and TD3206
- N-minute data set: TD9649 and additional dataset covering 1973-1979

Other sources were NRCS (USDA) and local datasets, which included data from:

- San Bernardino County Flood Control District, CA
- Riverside County Flood Control and Water Conservation District, CA
- NWS's California-Nevada River Forecast Center at Sacramento, CA
- California Department of Water Resources (CDWR) Automated Local Evaluation in Real Time (ALERT) precipitation gauges
- ALERT hourly data from Maricopa County Flood Control District, AZ
- U.S. Geological Survey (USGS) dense precipitation gauge network from the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA).

Various supplementary stations provided information where no or limited data were previously available, i.e. in high elevations and south of the United States border. SNOTEL (SNOpack TELemetry) provided information in high elevations of the project area. The SNOTEL network of stations at high altitudes (6000 - 11,000 feet) is operated by the United State's Department of Agriculture's (USDA) National Resources Conservation Service (NRCS). Additional daily data south of the United States border were obtained through the cooperation of Mr. Jorge Sanchez-Sesma, Instituto Mexicano de Technologia del Agua, Mexico City, Mexico.

Table 4.1.1. Number of stations in each state in the project area.

State	Daily	SNOTEL	Hourly	N-min
Arizona	270	13	68	5
Southeastern California	122	1	75	7
Nevada	114	26	39	5
New Mexico	239	11	76	3
Utah	212	67	42	4
Border states*	484	64	181	3
Baja, Mexico	31	n/a	n/a	n/a
Chihuahua, Mexico	10	n/a	n/a	n/a
Sonora, Mexico	22	n/a	n/a	n/a
Total	**1504**	**182**	**481**	**27**

*Border states include parts of California, Colorado, Idaho, Oklahoma, Oregon, Texas and Wyoming that are directly adjacent to the project core area.

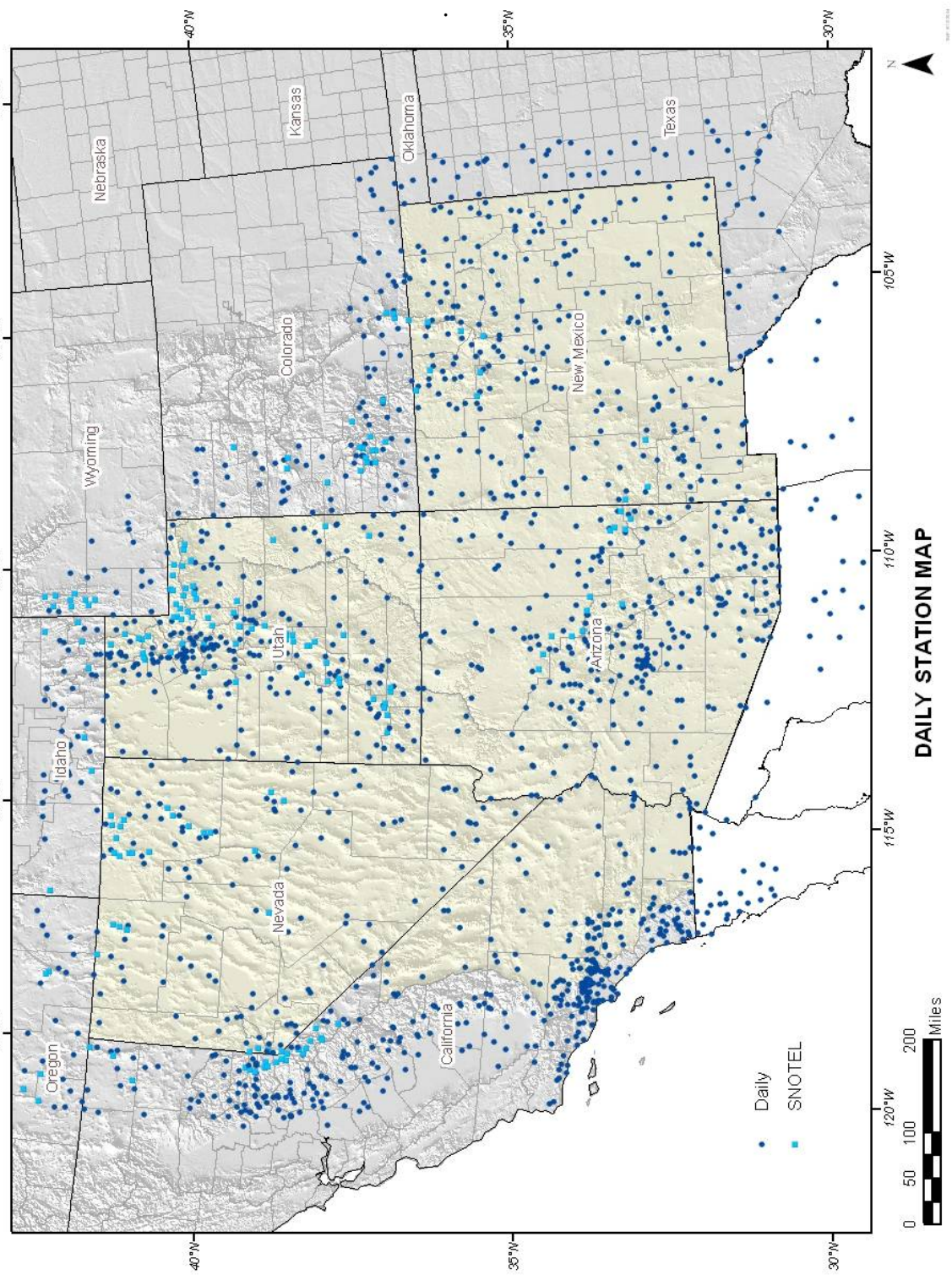

Figure 4.1.1. Map of daily and SNOTEL stations for NOAA Atlas 14 Volume 1

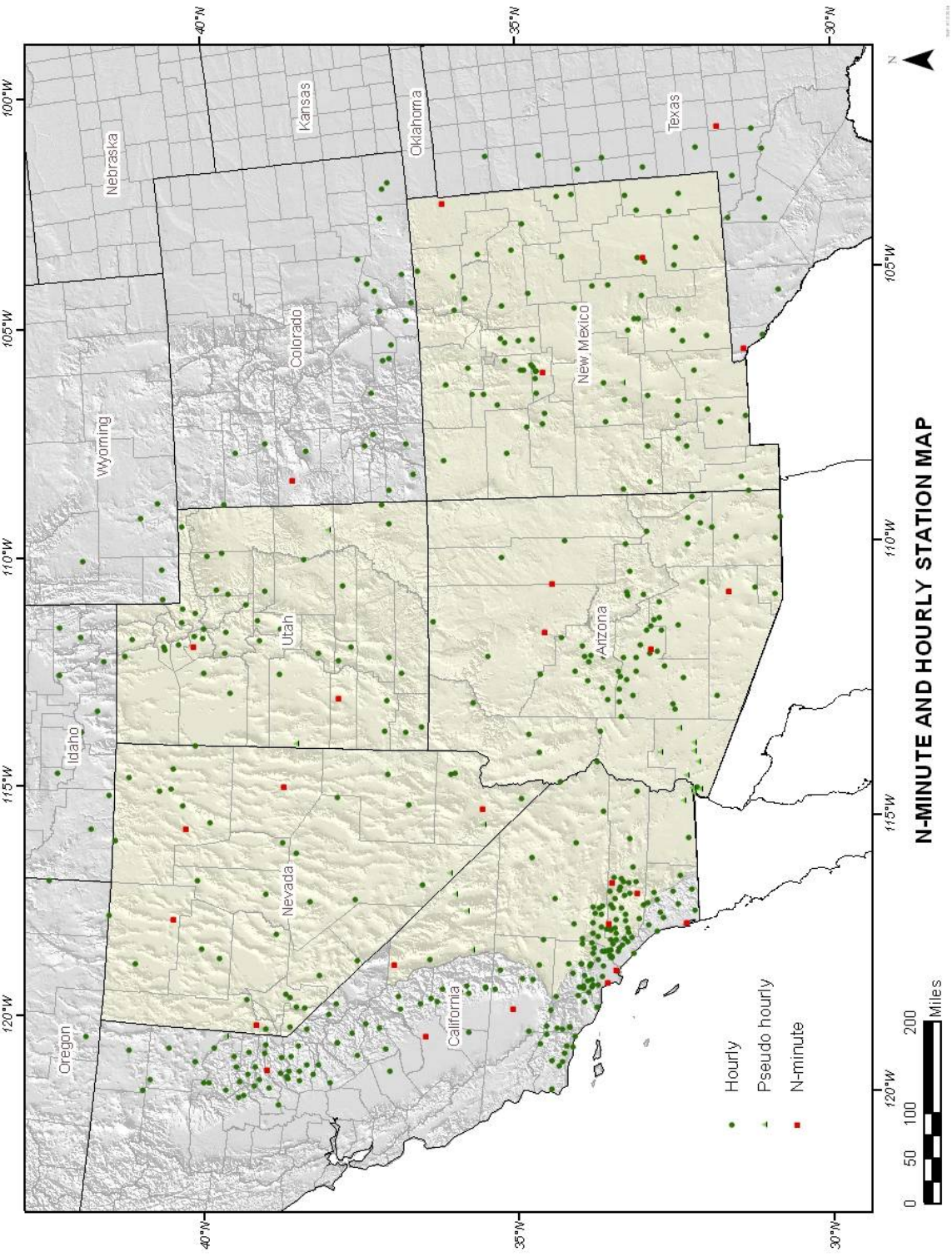

Figure 4.1.2. Map of hourly and n-minute stations for NOAA Atlas 14 Volume 1.

Record length. Record length may be characterized by the entire period of record or by the number of years of useable data within the total period of record (data years). For this project, only daily stations with 20 or more data years and hourly stations with 15 or more data years were used in the analysis. The records of these stations extend through December 2000 and average 54 years in length for daily stations and 37 years for hourly (Table 4.1.2). Figures 4.1.3 and 4.1.4 show the number of data years by percent of stations for the daily and hourly data. N-minute records used in the analysis had 14 to nearly 100 years of data with records extending through May 1997. At the time of this project the n-minute data at NCDC had not been updated beyond 1997. Eight n-minute stations had more than 80 years of data. (See Appendix A.7 for a complete list of stations.)

Table 4.1.2. Information for daily and hourly datasets through 12/2000 and n-minute datasets through 5/1997.

	Daily	**Hourly**	**N-minute**
No. of stations	1441 (+182 SNOTEL) (+63 Mexico)	481	27
Longest record length (yrs) (Station ID)	108 (29-8535)	62 (04-4211)	88 (02-6481)
Average record length (yrs)	54*	37	36

*not including SNOTEL or Mexico stations

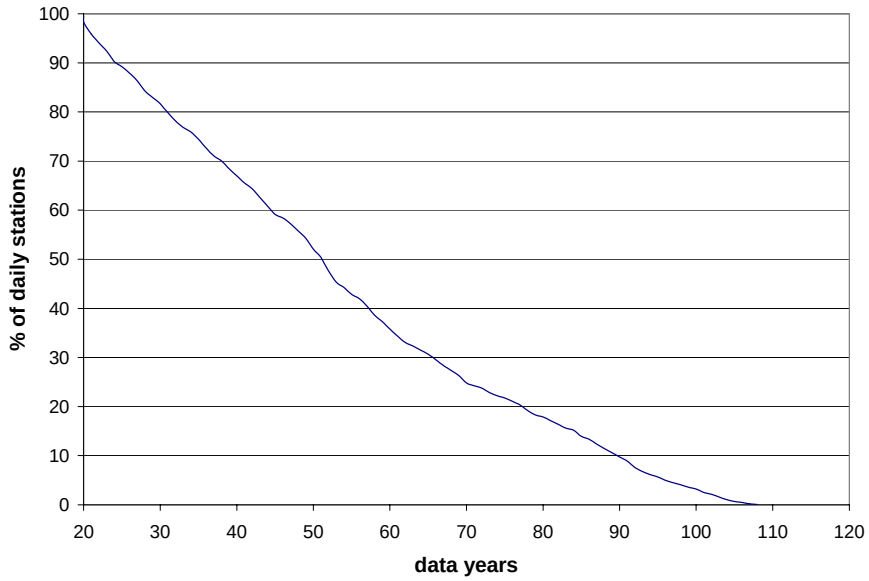

Figure 4.1.3. Plot of percentage of total number of daily stations used in NOAA Atlas 14 Volume 1 versus data years.

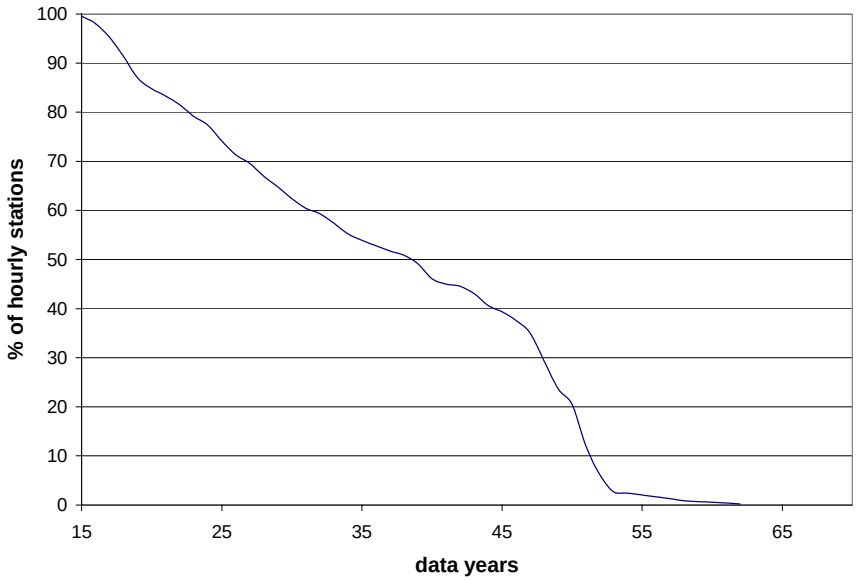

Figure 4.1.4. Plot of percentage of hourly stations used in NOAA Atlas 14 Volume 1 versus data years.

N-minute data. N-minute data are precipitation data measured at a temporal resolution of 5-minutes that can be summed to various "n-minute" durations (10-minute, 15-minute, 30-minute, and 60-minute). Because of the small number of n-minute data available, n-minute precipitation frequencies were estimated by applying a linear scaling to 60-minute data. The linear scaling factors were developed using ratios of n-minute quantiles to 60-minute quantiles from 27 co-located n-minute and hourly stations divided into 6 regions (Figure 4.1.5). The ratios were calculated and averaged for each region. Since they were found to be essentially the same regardless of region and frequency, the ratios for each duration were averaged over the 6 regions and all annual exceedance probabilities and then applied to the entire project area.

The ratios are consistent with other studies. Table 4.1.3 shows the n-minute ratios (n-min/60-min) computed for NOAA Atlas 14 Volume 1 and those reported in NOAA Atlas 2 (Miller et al., 1973) (herein after referred to as NOAA Atlas 2) for 5, 10, 15, and 30 minutes. Also shown in Table 4.1.3 are the ratios used by Arkell and Richards (1986), who computed values for a comparable geographic area, but did not include California.

Figure 4.1.5. Regional groupings for n-minute data for NOAA Atlas 14 Volume 1.

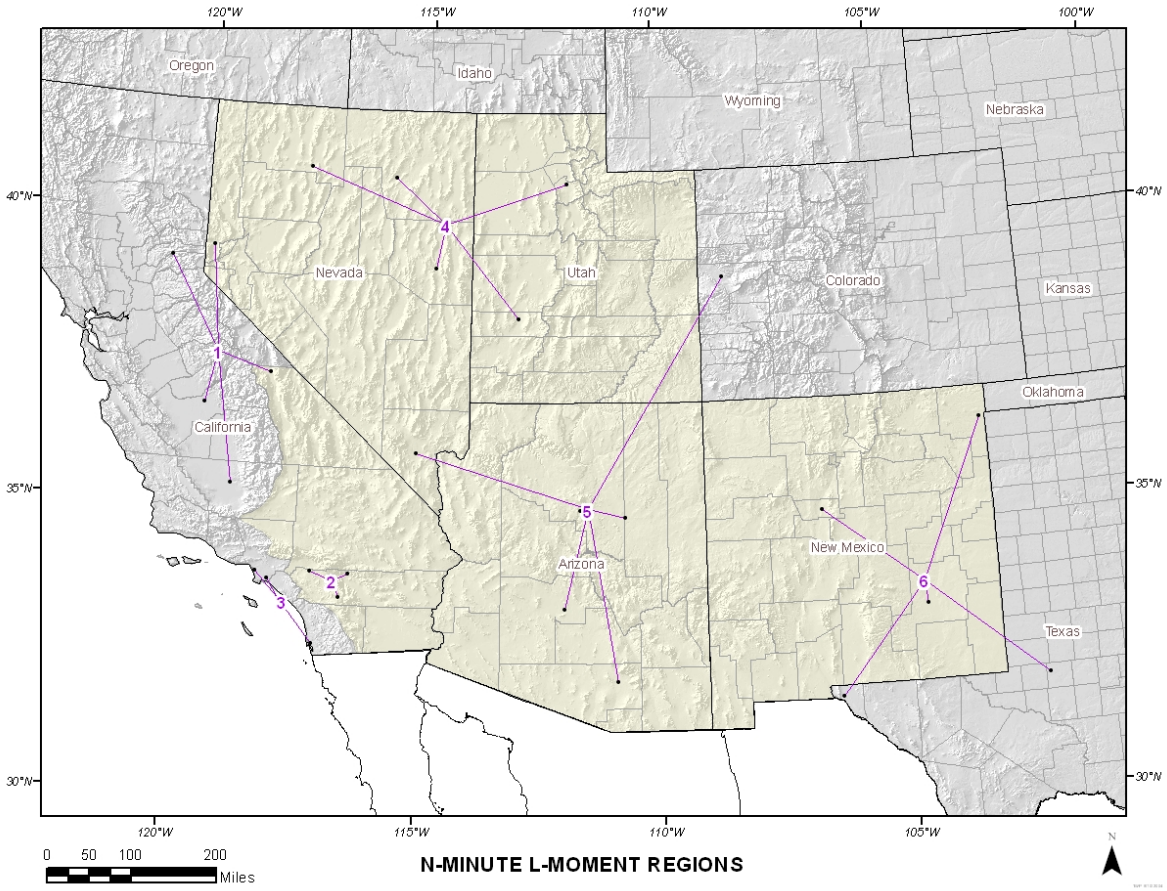

Table 4.1.3. N-minute ratios: 5-, 10-, 15- and 30-Minute to 60-Minute.

	5-min	10-min	15-min	30-min
NOAA Atlas 14 Volume 1	**0.318**	**0.484**	**0.600**	**0.808**
NOAA Atlas 2	*0.29*	*0.45*	*0.57*	*0.79*
Arkell and Richards, 1986	*0.34*	*0.52*	*0.62*	*0.82*

SNOTEL data. SNOTEL stations provide precipitation data in the higher elevations where in NOAA Atlas 2 there was no information. The number and quality of the data were insufficient for computing higher order statistical moments directly and so the data were not used in the calculation of regional parameters. Rather, mean annual maxima for the 24-hour through 60-day durations at each location were computed for use in analysis and spatial interpolation processes. Precipitation frequency estimates for SNOTEL stations were calculated using the regional growth factors (RGFs), a dimensionless regional frequency distribution parameter derived from the regions in which they resided (Section 4.6.1), combined with the mean of thei annual maximum series at the SNOTEL station. The estimates were then used to anchor the spatial distribution of precipitation frequency

residuals that were the basis of the precipitation frequency grids (Section 4.8) to provide better accuracy at higher elevations.

Mexico data. Mexico data were included to provide spatial continuity across the southern border of the project area. The maximum record length of these daily data was 15 years. Annual maximum series were extracted from the data using 13 years as the minimum years of record so that a reasonable number of stations could be included. The data were not directly used in L-moment computations for the project area. The mean annual precipitation and mean annual maxima for the 24-hour through 60-day durations were computed and used in the spatial interpolation of the mean annual maxima values, but not the precipitation frequency estimates.

Multi-day/hour durations. Maxima for durations greater than 24-hour were generated by accumulating daily data. The multi-day maxima, 2-day through 60-day, were extracted in an iterative process where 1-day observations were summed and compared with the value of the previous summation shifted by 1 day. Multi-hour durations, 2-hour through 48-hour, were generated by accumulating hourly data. (See Section 4.1.3 for additional details on the annual maximum series and partial duration series extraction process.)

NOAA Atlas 2 data comparison. NOAA Atlas 14 Volume 1 used a total of 2,194 stations, which includes substantially more stations, 76% more, than were available to NOAA Atlas 2 (southeastern California could not be directly compared). Table 4.1.4 shows a comparison between the total number of stations used in each Atlas for the 4 complete core states, Arizona, Nevada, New Mexico, and Utah (southeastern California could not be directly compared). Many new stations also provided information in critical areas, where no data were available to NOAA Atlas 2, including 182 SNOTEL stations and 63 stations in Mexico. NOAA Atlas 2 used data through 1970, whereas this Atlas used data through 2000, vastly increasing the amount of data available. Some stations available for this Atlas had up to 30 more years of record than those used in NOAA Atlas 2. This allowed for the exclusion of shorter, less reliable data records. Figure 4.1.6 shows the number of years of record for daily stations used in each Atlas for the 4 core states, Arizona, Nevada, New Mexico, and Utah, (southeastern California could not be directly compared).

Table 4.1.4. Comparison of the total number of stations in Arizona, Nevada, New Mexico, and Utah (southeastern California could not be directly compared) that were used in NOAA Atlas 2 and NOAA Atlas 14 Volume 1.

Data type	NOAA Atlas 2	NOAA Atlas 14 Volume 1	Increase	% increase
Hourly	180	225	45	25%
Daily	563	835	272	48%
SNOTEL	0	182	182	
Mexico	0	63	63	
Total	**743**	**1305**	**562**	**76%**

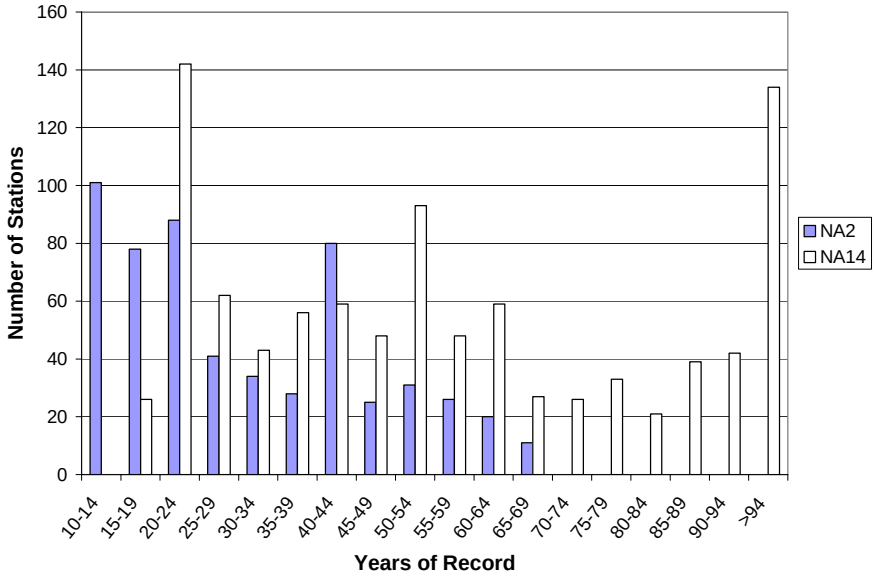

Figure 4.1.6. Comparison of the years of record at stations used in Arizona, Nevada, New Mexico, and Utah (southeastern California could not be directly compared) in NOAA Atlas 2 (NA2) and NOAA Atlas 14 Volume 1 (NA14) [Note: Mexico and SNOTEL stations are not included in chart.]

4.1.2. Conversions of data

Daily. Daily data has varying observation times. Maximum 24-hour amounts seldom fall within a single daily observation period. In order to make the daily and hourly data comparable, a conversion was necessary from 'observation day' (constrained observation) to 24 hours (unconstrained observation). Both NOAA Atlas 2 and Technical Paper 40 (Hershfield, 1961) used the empirically derived value of 1.13 to convert daily data to 24-hour data. Conversion factors for this project were computed using ratios of the 2-year quantiles computed from annual maxima series at 32 stations with concurrent hourly and daily data in the project area (note: at least 10 of these were first order stations). Time series for concurrent time periods were generated for 24-hour precipitation values summed from hourly observations and co-located daily precipitation observations. The series were analyzed separately using L-moments. Ratios of 2-year 24-hour to 2-year 1-day quantiles were then generated and averaged. The resulting conversion factor was comparable to results from a regression of daily-hourly monthly maxima that occurred on the same day. The regression was not directly used since there were not enough data to produce a reliable result. The conversion factor used in this project was 1.14, which is consistent with the conversion factor used in NOAA Atlas 2 and Technical Paper 40. Similarly, a 2-day to 48-hour conversion factor of 1.03 was generated for NOAA Atlas 14 Volume 1. This value had not been previously calculated in the other studies. All daily and 2-day data, including SNOTEL data, were converted to equivalent 24-hour and 48-hour unconstrained values, respectively.

Hourly. In order to make hourly and 60-minute data comparable, a conversion was necessary from the constrained ‘clock hour' to unconstrained 60-minute and from 2 hours to 120-minute. Conversion factors were computed using ratios of the 2-year quantiles computed from annual maxima series at 12 stations with co-located hourly and n-minute stations in the project area. Time series from concurrent time periods were generated for 60-minute precipitation values summed from n-minute observations and co-located hourly precipitation observations. The series were analyzed separately using L-moments. Ratios of 2-year 60-minute to 2-year 1-hour quantiles were generated and averaged. The

resulting conversion factor was 1.12 for 1-hour to 60-minute and 1.03 for 2-hour to 120-minute. This is in agreement with NOAA Atlas 2 and Technical Paper 40 which used 1.13 for the 1-hour to 60-minute conversion (no conversion was provided for 2-hour to 120-minutes in those studies).

4.1.3. Extraction of series

Two methods were used for extracting series of data for the analysis of precipitation frequency: **Annual Maximum Series (AMS)** and **Partial Duration Series (PDS)**.

The AMS method selected the largest single case that occurred in each calendar year of record. If a large case was not the largest in a particular year, it was not included in the series.

The PDS method recognized that more than one large case may occur during a single calendar year. For this Atlas, the largest N cases in the entire period of record, where N is the number of years of data, were selected to create the partial duration series. More than one case could be selected from any particular year and a large case that is not the largest in a particular year could appear in the series. Such a series is also called an annual exceedance series (AES) (Chow et al., 1988).

Differences in the meaning of the results of analysis using these two different types of series are discussed in Section 3.2. Average empirical conversion factors were developed to provide PDS-based results from the AMS-based results (see Section 4.6.3). The data series used in the analysis (and associated documentation) are provided through the Precipitation Frequency Data Server which can be found at http://hdsc.nws.noaa.gov/hdsc.

The procedure for extracting maxima from the dataset used specific criteria. The criteria, described below, ensured that each year had a sufficient number of data, particularly in the assigned "wet season", to accurately extract statistically meaningful values. The "wet season" for each location was defined as the months in which extreme cases were mostly likely to occur and was assigned by assessing histograms of annual maximum precipitation for each homogeneous region (Tables 4.1.5 and 4.1.6).

Criteria for hourly annual maximum series. For all hourly durations (1-hour through 48-hours), the highest value in each year was extracted as the annual maximum for that particular year. Cases that spanned January 1st were assigned to the date on which the greatest hourly precipitation occurred during the corresponding duration.

A month was invalid and the maximum precipitation for that month was set to missing:

- if the hours of available data in a month were less than the duration hours
- if 240 hours or more in a month were missing and the maximum precipitation for the month <= 0.01 inches
- if 360 or more hours in a month were missing and the maximum precipitation for the month was less than 33% of the average precipitation for that month at that station
- if 50% or more hours (for a specific duration) were missing

Also, if more than 50% of the months in the wet season for a given region were missing, then the maximum precipitation for the year was set to missing.

Table 4.1.5. "Wet season" months for daily regions of NOAA Atlas 14 Volume 1.

Region	start month	end month
Daily Regions		
1	10	6
2	10	6
3	10	6
4	4	10
5	9	6
6	4	10
7	4	10
8	10	3
9	10	3
10	10	6
11	8	6
12	3	11
13	3	11
14	8	6
15	4	10
16	11	3
17	11	3
18	11	3
19	7	3
20	7	3
21	7	3
22	3	11
23	7	3
24	7	11
25	7	11
26	7	11
27	11	3
28	11	3
29	11	3
30	11	3
31	11	3
32	11	3
33	7	3
34	7	3
35	7	3
36	7	3
37	7	12
38	7	12
39	5	10
40	7	3
41	7	3
42	7	3
43	7	3
44	7	12
45	6	10
46	5	10
47	5	10
48	5	10
49	5	10
50	5	10
51	7	12
52	7	12
53	7	12
54	7	12
55	6	10
56	5	10
57	6	10
58	11	3
59	6	10
A1	7	12
A2	7	12
A3	6	10
A4	6	10
A5	7	11
A6	10	6

Table 4.1.6. "Wet season" months for hourly regions NOAA Atlas 14 Volume 1.

region	start month	end month
Hourly Regions		
1	10	6
2	4	10
3	10	6
4	8	6
5	4	10
6	7	11
7	7	3
8	7	12
9	5	10
10E	7	3
10W	7	3
11	7	3
12	7	12
13	6	10
14	5	10
15	11	3
16	10	3
17	10	3
18	9	6
19	4	10
20	11	3
21	3	11
22	11	3
23	8	6
24	11	3

Criteria for daily annual maximum series. An annual maximum was extracted for daily durations (1-day through 60-day), if at least 50% of the months in the assigned wet season and at least 50% of the data for the accumulated period were present. The highest value in each year was extracted as the annual

maximum for that particular year. Cases that spanned January 1st were assigned to the date on which the greatest daily precipitation occurred during the corresponding duration.

In addition, the following criteria applied:

1-day:
If all the days in the month were missing, or if more than 10 days of the month were missing and the maximum precipitation for the month was 0.00", or if more than 15 days were missing and the maximum for the month was less than 30% of the average 1-day maximum precipitation for that month over the period of record at that station, then that month was set to missing.

2-day:
If there was only 1 day of data for the month and the rest of the days were missing, or if more than 10 days of the month were missing and the maximum precipitation for the month was 0.00", or if more than 15 days were missing and the maximum for the month was less than 30% of the average 2-day maximum precipitation for that month over the period of record at that station, then that month was set to missing.

4-day:
If more than 96% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.3" or less, then that year was set to missing.

7-day:
If more than 93% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.3" or less, then that year was set to missing.

10-day:
If more than 93% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.35" or less, then that year was set to missing.

20-day:
If more than 88% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.35" or less, then that year was set to missing.

30-day:
If more than 82% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.45" or less, then that year was set to missing.

45-day:
If more than 73% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.45" or less, then that year was set to missing.

60-day:
If more than 64% of the days in a given year were missing, or if 50% of the days of the year were missing and the maximum precipitation for the year was 0.45" or less, then that year was set to missing.

Criteria for partial duration series. The criteria listed above also apply for deciding whether a month or year has enough data to be included in the extraction process for a partial duration series. Cases that spanned January 1st were assigned to the date on which the greatest precipitation observation occurred during the corresponding duration.

Precipitation accumulations for each duration were extracted and then sorted in descending order. The highest N accumulations for each duration were retained where N is the number of actual data years for each station.